MODIS CALIBRATION PROGRAM AT THE UNIVERSITY OF ARIZONA

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Presented at the MODIS Calibration Review
NASA/GSFC

July 18, 1995

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THE REMOTE SENSING GROUP AT THE UNIVERSITY OF ARIZONA

The Remote Sensing Group (RSG) comprises 4 FTE faculty, 3.5 FTE staff, and 7 graduate students plus, from time to time, visiting scholars and postdocs.

The main source of support is from MODIS ($645 K FY'95), additional support comes from ASTER and SeaWiFS.

ASTER, in addition to calibration, concerns the development of software for Level-2 surface radiance and reflectance products.

Considerable cost savings incur because vicarious calibration activities are common to both MODIS and ASTER.

LABORATORY FACILITIES AND EQUIPMENT

A black laboratory with source room, two optics laboratories, an instrument assembly room and a room with a clean bench

Automated 3-axis goniospectroradiometric facility with a polarization capability for characterizing field reference panels and calibrating field radiometers

Optronic double monochromator for accurate spectral-filter characterization, relative spectral response measurements, and directional-hemispheric reflectance measurements

40-inch diameter spherical-integrating source for radiometer calibration and chacterization

A stable VNIR transfer radiometer for cross comparing EOS calibration sources

FACILITIES AND EQUIPMENT FOR FIELD WORK

Air-conditioned mobile laboratory containing two 10-kW generators, an UPS, computer work space and storage space

A Cessna aircraft with a 15-inch port for nadir and near-nadir viewing and a mount for radiometers are available for our use.

The following are available: Barnes, Exotech (3), Reagan, Spectron and ASD radiometers; an auto-tracking solar radiometer with polarization capability; a SWIR radiometer; a solar aureole camera; Spectralon and $BaSO_4$ reference panels; an automated meteorological station, a video camera for use with aircraft-mounted radiometers; and an all-sky camera. A BRDF camera, SWIR and TIR radiometers and an accurate diffuse-to-global irradiance meter are under development.

COMPUTER AND COMPUTER-RELATED FACILITIES AND EQUIPMENT

One large computer room housing five Sun SPARCstation workstations with several tape drives and other peripherals. Three other Sun SPARCstation workstations in faculty offices. All workstations are equipped with UPS. Disk space totals about 24 GB. RAM varies from 256 MB to 32 MB. Four machines are MP capable.

Four 486-class notebook computers for faculty use, two of which also control lab instruments. Three 486-class portable computers for instrument control. Two Pentium computers for lab and network server use.

All computers are networked by thin Ethernet which is bridged to the campus network by a spread spectrum radio bridge. Two networked laser printers and one color-ink-jet printer.

COMPUTER SOFTWARE

Sun - OS: Solaris 2.X (X = 4 and 3) except for one SunOS 4.1.3_U1

Applications: IDL (3.6.1 and 4.0)
- Erdas Imagine 8.2
- Unix WordPerfect 6.0
- Lotus 123 for Sun 1.2
- LabView for Sun 3.1.1
- AutoCAD for Sun, rel 12c1
- Sun C and Fortran compilers

PC - OS: DOS 6.X with Windows 3.X, Windows NT, or OS/2 ver 3.0

Applications: WordPerfect 6.1
- Lotus 123 5.0
- IDL for Windows 4.0
- LabView for Windows N/T 3.1
- C and Fortran compilers
- Generic CAD
- Sun PC-NFS Networking sw

RECENT PUBLICATIONS

The booklet of 13 papers, contained in your handout, is a compilation of peer-reviewed and proceedings papers generated during the past two years by faculty and students of the RSG.

The topics cover a broad range of subjects, for example:

1. A radiative transfer code for a spherical atmosphere and inversion methods for deriving aerosol parameters from solar aureole data.
2. Instrumentation developments of a SWIR spectroradiometer, a solar aureole camera, and a water-vapor radiometer.
3. Vicarious calibration methods for AM-1 sensors.
4. Suggestions for integrating vicarious calibration with on-board calibrator results.
5. Solar-radiation-based calibration methods, and their application to SeaWiFS and an aircraft Daedalus scanner.

ROLE OF THE RSG IN MODIS CALIBRATION

Preflight calibration and cross calibration

Refining reflectance- and radiance-based vicarious calibration methods

Vicarious cross comparison

Calibration data integration

Participating in EOS calibration peer reviews, MCST reviews, EOS Cal/Val meetings, Calibration Plan development and presentation, MODIS PDR, CDR, EM test results, etc., assisting in special studies, e.g., filter position determination, stray light, and preflight calibration.

PREFLIGHT CALIBRATION AND CROSS CALIBRATION

Solar-Radiation-Based Calibration

- Calibrates solar diffuser and diffuser monitor with the sun
- Tested on SeaWiFS - waiting for launch for results
- Proposed for MODIS - schedule and risk concerns but favored by Jim Young of SBRC and in the current SBRC Cal Plan. Unlikely to be used.

Transfer Radiometers

- Cross-calibration of the calibration sources for
  - MODIS: 1.0-m diameter SIS at SBRC manufactured by Labsphere
  - ASTER: 1.0-m diameter NEC SIS
  - MISR: 1.65-m diameter SIS at JPL manufactured by Labsphere
- Stable, transportable radiometers covering:
  - VIS-NIR: 7 MODIS bands between 413 and 869 nm
  - SWIR: 4 MODIS bands and 5 ASTER bands

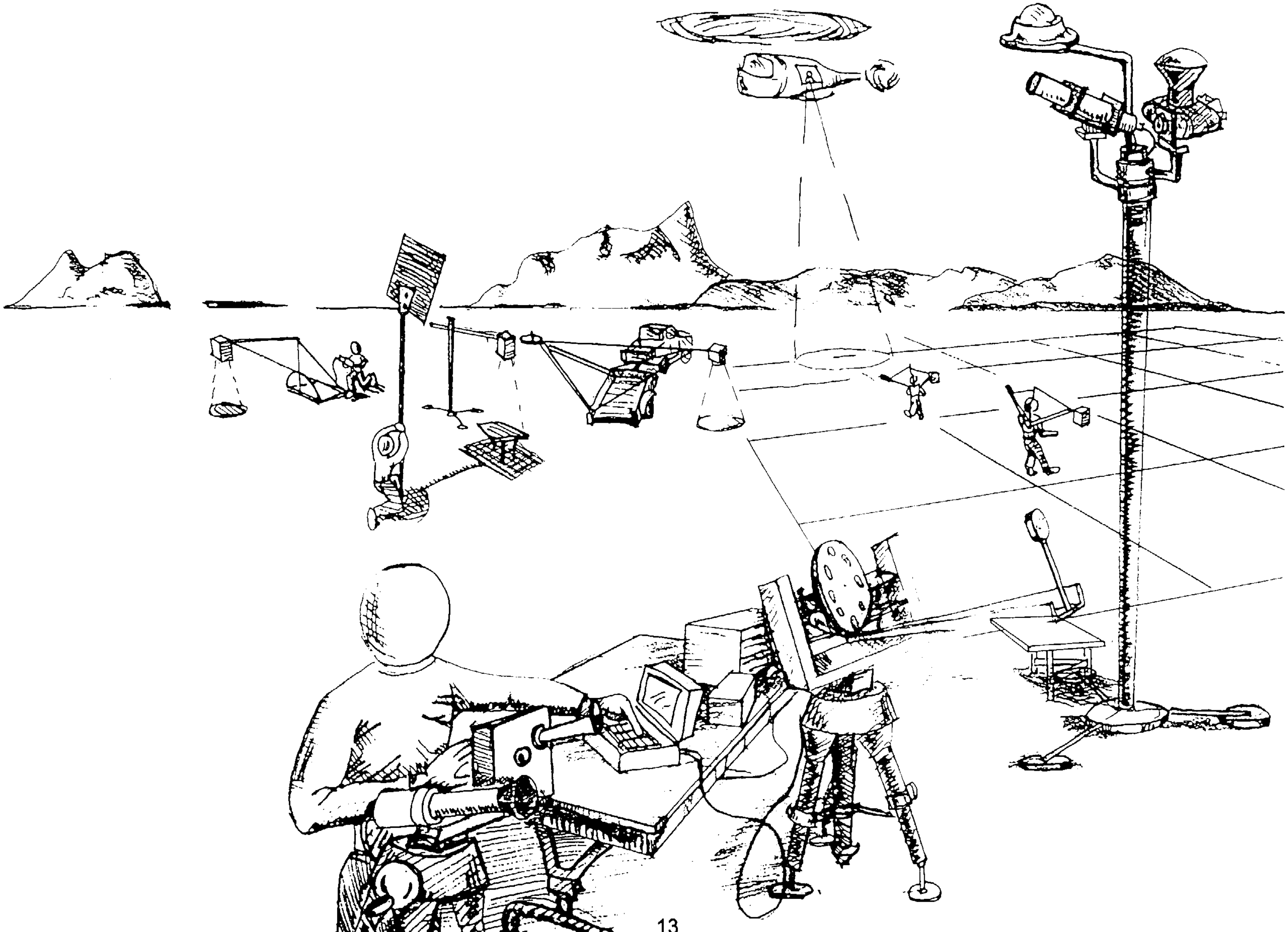
IMPORTANCE OF VICARIOUS CALIBRATION TO MODIS AND EOS

Presently there is concern that the MODIS OBCs may not meet the MODIS calibration requirements because:

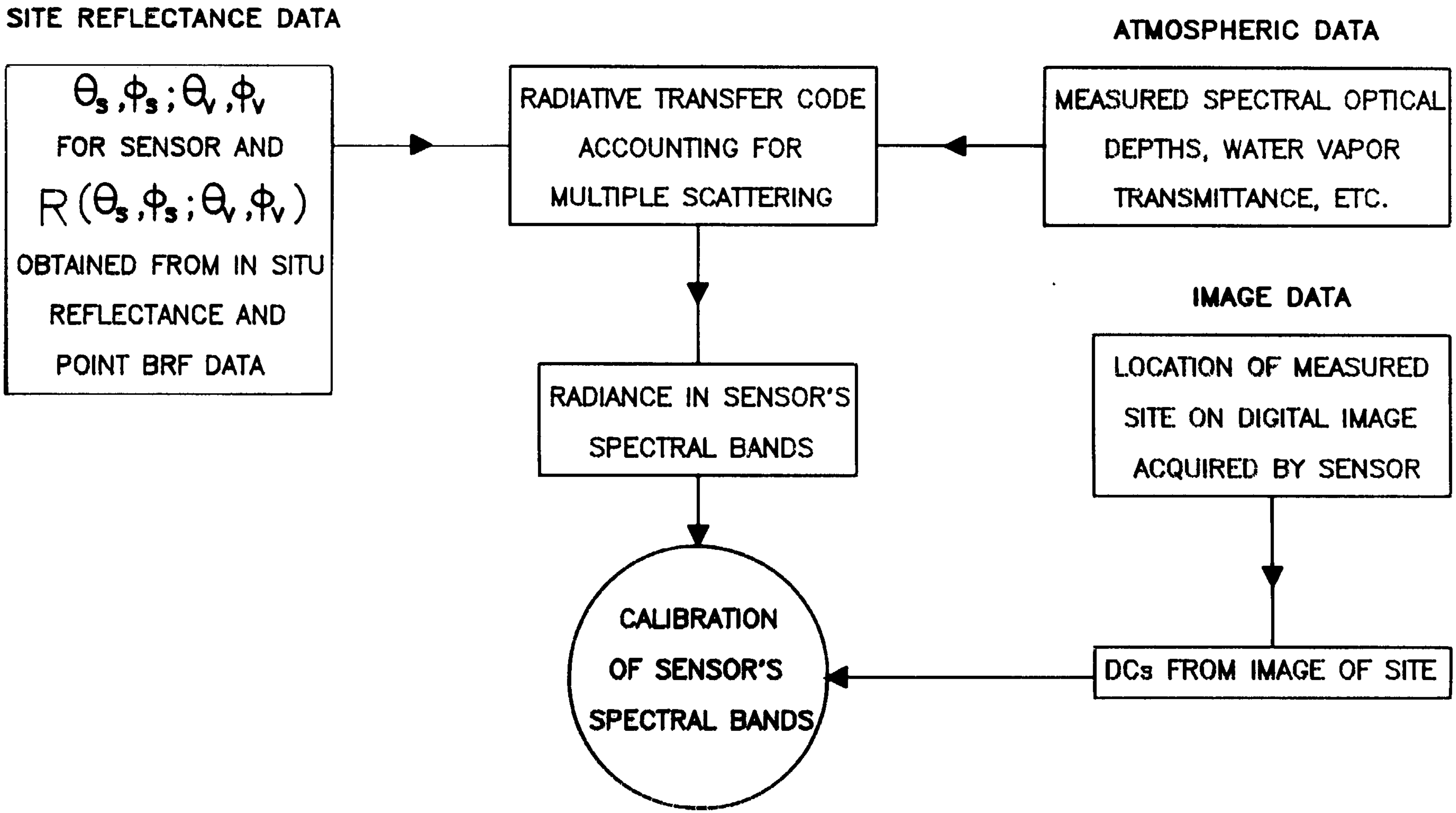
1. There is no present plan to calibrate the SD/SDSM using a method that will provide a 2% reflection uncertainty in the 0.4 to 2.5 μm range.
2. The OBCs are new, untested, complicated systems that have not been checked during the EM test program. There were sufficient questions regarding the results of the EM tests that were performed on MODIS, for there to be concern regarding the performance of the SRCA and SD/SDSM.
3. There are likely to be several questions, for example, the size-of-source effect, that can best be resolved by vicarious calibration and cross-comparisons between AM-1 sensors.
4. There is some doubt that the SWIR and TIR calibrations can be traced to NIST to the required uncertainty.

Vicarious calibration in the solar reflective range can probably provide an uncertainty of about 2% with respect to NIST and 3% with respect to the sun. In the TIR the goal is an uncertainty of 1%.

ILLUSTRATION OF FIELD EQUIPMENT



REFLECTANCE-BASED CALIBRATION

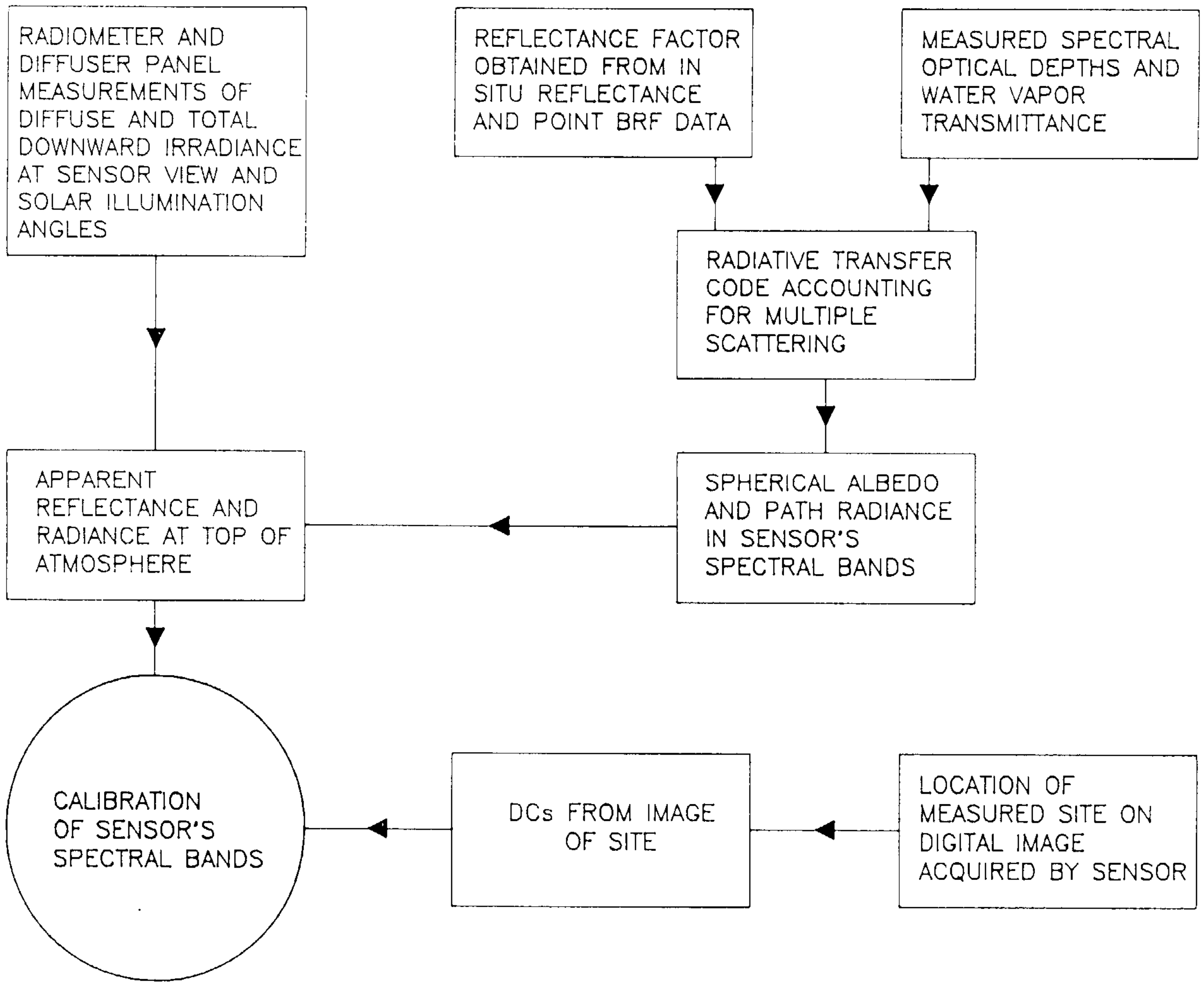


Error sources for reflectance-based method, with reference to solar-exoatmospheric irradiance.* The values are quoted as percentages.

Source	Present		Anticipated	
	Error	Total error	Error	Total error
Ground reflectance measurement		2.1		1.2
Reference panel calibration (BRF)	2.0		1.0	
Diffuse field correction	0.5		0.5	
Measurement errors	0.5		0.5	
Optical depth measurements	5.4	1.1	5.4	1.1
Extinction optical depth	5.0		5.0	
Partition into Mie and Rayleigh	2.0		2.0	
Absorption computations		1.3		1.3
O_3 amount error	20.0		20.0	
Choice of aerosol complex index	2.0	2.0	1.5	1.5
Choice of aerosol size distribution		3.0		1.5
Type				
Size limits	0.2		0.2	
Junge parameter	0.5		0.5	
Vertical distribution	1.0	1.0	1.0	1.0
Non-lambertian ground characteristic	1.2	1.2	0.5	0.5
	0.1	0.1	0.1	0.1
Non-polarization v. polarization code	1.0	1.0	1.0	1.0
Inherent code accuracy	0.2	0.2	0.2	0.2
Uncertainty in the value of μ_{sun}				
Total error (root sum of squares)		4.9		3.3

*The first and third columns of values refer to errors in the quantities on the left. The second and fourth columns of values are the resultant errors in the radiance at the sensor.

IRRADIANCE-BASED CALIBRATION

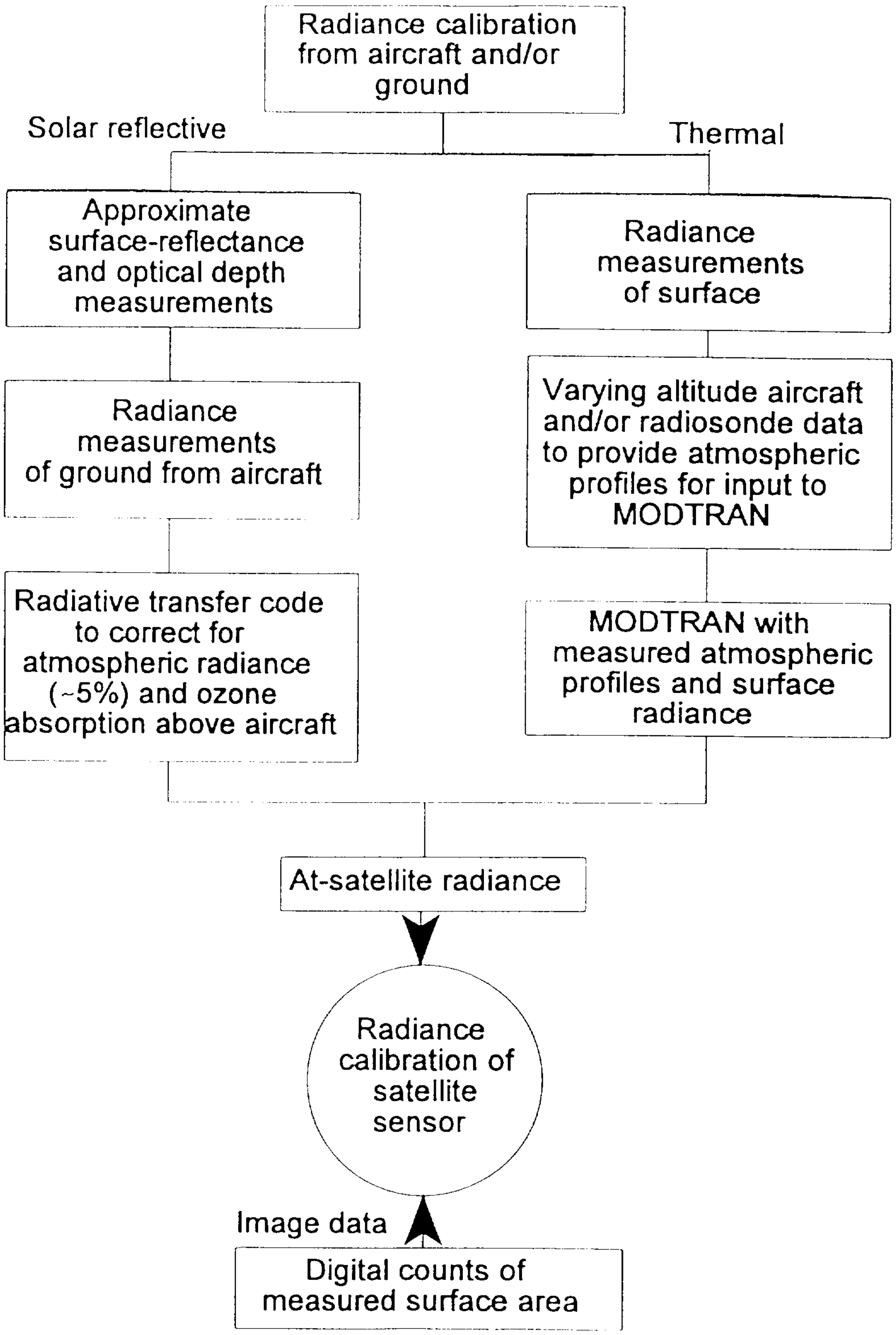


Error sources for irradiance-based method, with reference to solar-exoatmospheric irradiance.* The values are quoted as percentages.

Source	Present		Anticipated	
	Error	Total error	Error	Total error
Extinction optical depth	5.0	1.0	5.0	1.0
Diffuse-to-global ratio measurement		2.3		1.7
Field measurement	2.0	0.5	2.0	0.5
Blocked diffuse component	2.0	0.5	2.0	0.5
Extrapolation to new angles	1.0	0.25	1.0	0.25
Panel BRF correction (θ_{sun} ~ 50°)	2.2	2.2	1.5	1.5
Ground reflectance measurement	2.1	2.1	1.2	1.2
Non-lambertian ground characteristic	1.2	1.2	1.2	1.2
Spherical albedo and atmospheric reflectance		1.0		1.0
Atmospheric model error	1.0		1.0	
Uncertainty in μ_{sun} and μ_{view}	0.4	0.1	0.4	0.1
Total error (root sum of squares)		3.5		2.8

*The first and third columns of values refer to errors in the quantities on the left. The second and fourth columns of values are the resultant errors in the radiance at the sensor.

RADIANCE-BASED CALIBRATION



VICARIOUS CALIBRATION RADIOMETERS

Aircraft mounted for radiance-based calibrations or used on ground

1. VINIR
   - Silicon "trap" detector based radiometer
   - No optics other than apertures, filters, and detectors
   - Non-imaging single 4.6 degree FOV
   - Multiple narrow (10-15 nm) interference filters

2. VINIR - SWIR
   - ASD FieldSpec FR portable spectrometer
   - Non-imaging single 1 degree FOV with fiber optic cable
   - Silicon linear array and 2 scanning monochromators with InGaAs detectors
   - Several nanometer sampling interval

3. TIR
   - In preliminary design
   - Probable single element detector
   - Interference filter(s)
   - Internal calibration blackbody(s)

Error sources for radiance-based method, with reference to NIST standards.* The values are quoted as percentages.

Source	Present: Error	Present: Total error	Anticipated: Error	Anticipated: Total error
Radiometer calibration		2.5		1.6
Panel calibration	2.0		1.0	
Lamp calibration	1.3		0.9	
Scale uncertainty	1.2		0.8	
Transfer uncertainty	0.5		0.5	
Lamp positioning	0.3		0.3	
Lamp current stability	0.5		0.5	
Voltage measurement error	0.5		0.5	
Measurement accuracy		1.3		0.9
Data logger accuracy	0.5		0.5	
Radiometer stability	0.5		0.5	
Pointing angle errors	1.1		0.5	
Correction for altitude difference		<0.1		<0.1
Uncertainty in the reflectance-based method	4.9		3.3	
Total error (root sum of squares)		2.8		1.8

*The first and third columns of values refer to errors in the quantities on the left. The second and fourth columns of values are the resultant errors in the radiance at the sensor. Work is underway to reduce the underlined values.

VICARIOUS CALIBRATION SOFTWARE DEVELOPMENT

CURRENT STATUS

Separate codes for:
- Langley processing
- Water vapor retrieval
- Aerosol size distribution retrieval
- Radiative transfer code

Image processing software to handle data

GOAL

Create integrated package
- Raw data in and calibration coefficient out
- No user interaction
- Rules-based approach

All code converted to the C language

Use an IDL wraparound for user interface

VICARIOUS CALIBRATION SOFTWARE DEVELOPMENT (Contd.)

WHY?

Speed processing

Repeatable results

Reduce user related uncertainties

Improve current method
- Better aerosol inversion
- Simplify cross-calibration software

Include results from new instrumentation
- solar aureole results
- BRF camera data
- Diffuse-to-global meter data
- SWIR atmospheric optical depths

VICARIOUS CALIBRATION SOFTWARE DEVELOPMENT (Contd.)

WORK COMPLETED

Radiative transfer code rewritten in C

Rules-based Langley processing code developed

Imagery display in IDL

Langley processing software in IDL

WORK IN PROGRESS

SPOT-TM cross-calibration test

Integration of columnar water vapor and optical depth retrieval

Integration of optical depth and aerosol retrieval

VICARIOUS CROSS COMPARISONS

Cross comparisons have been simulated in the solar-reflective range between MODIS, ASTER, MISR, and Landsat using 6S. Mid-latitude summer and winter atmospheres with visibilities of 5 km and 100 km were used with a solar zenith angle of 45° and a nadir view angle. An approximation to the spectral reflectance of Lunar Lake and Railroad playa was assumed. An elevation of 6000 ft. was used and a homogeneous target assumed.

PRELIMINARY RESULTS OF CROSS-COMPARISON SIMULATIONS

With overlapping bands, for wavelengths greater than about 500 nm, comparisons between bands from the above sensors were stable to within about 1% for all four atmospheric conditions. These results, if verified, would aid in reconciling any differences noted between the in-flight calibration of the above sensors and thus improve the consistency of similar data products from these sensors.

An accurate comparison can be achieved between sequential, nominally identical sensors in a series, provided they can be maneuvered to be within about 10 minutes of each other in the same inclination orbit for a few weeks.

Over extended wavelength ranges, comparisons between different MODIS bands, not in absorption regions, showed a similar 1% stability. This could prove to be of value as a simple way to check relative band-to-band calibration in flight -- of critical importance for data products produced by ratioing methods.

Considerable work needs to be done to verify these early results, and estimate the range of conditions under which they are valid.

INTEGRATION OF VC AND OBC RESULTS

An estimated 30 to 40 VCs are likely to be conducted each year for many of the MODIS bands.

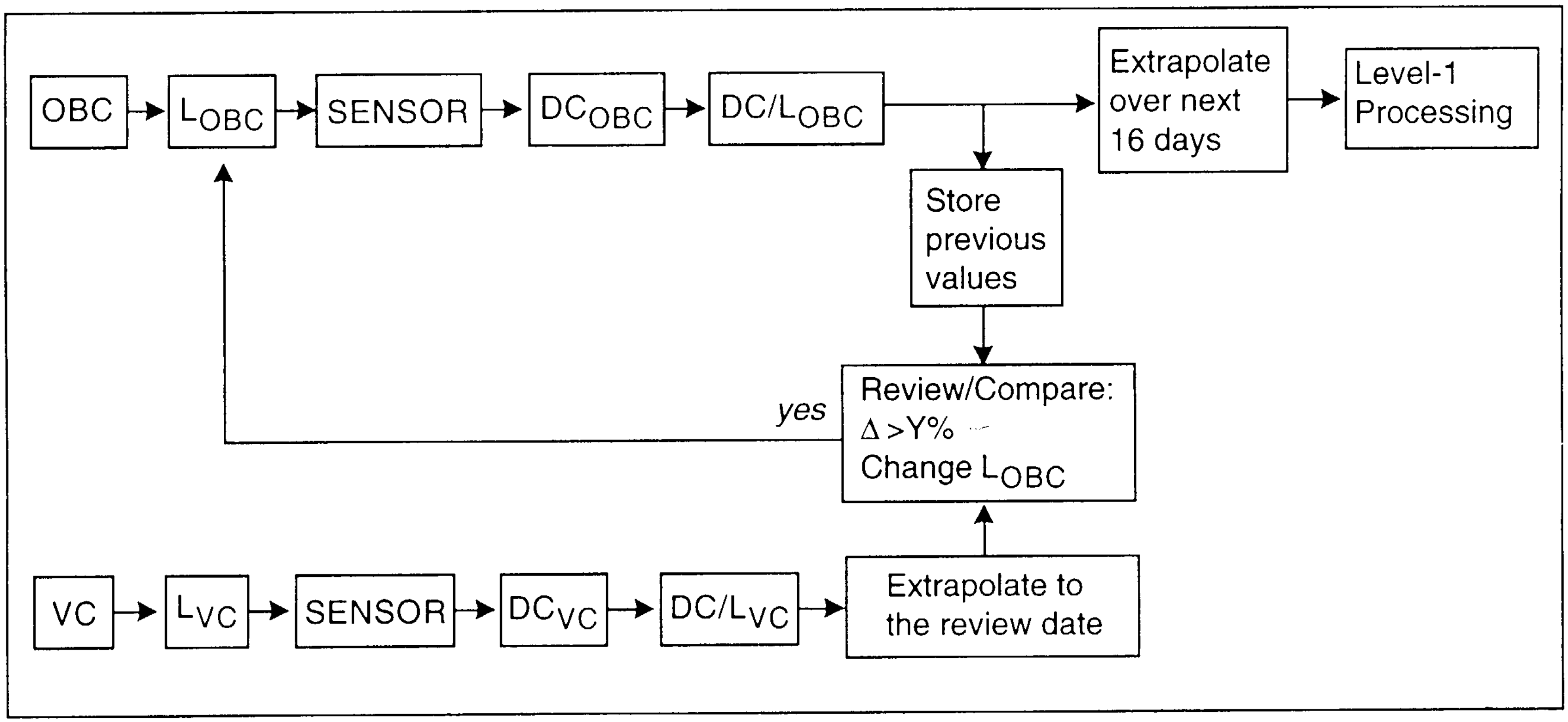
These calibrations simulate, more closely than any others, the operational image acquisition mode of MODIS. In this sense they are the most reliable.

VCs are also reliable from the standpoint of being correctable with time if one of the measuring instruments fails -- a big advantage compared to OBCs.

For these reasons a method should be developed to include VC results, as they become available, in the production of the Level-1B data.

The following is one suggested way which produces a final product which is smoothly varying with time, and represents the best estimate of the calibration coefficients with time.

FLOW CHART OF LEVEL-1B PRODUCTION



UNIQUE CONTRIBUTIONS

Pioneered vicarious calibration using reflectance-based and radiance-based methods for small IFOV, satellite and aircraft sensors; RSG results used by SPOT

First to suggest, in a journal article, methods for combining calibration coefficients

First to describe, in a journal article, the radiometric instability introduced due to filter shifts in the vicinity of Fraunhofer lines, results applied to MODIS

First to implement solar-radiation-based calibration for satellite and aircraft sensors and field radiometers, a method which is suggested in the SBRC Cal Plan for MODIS

First to propose a ratioing radiometer approach to on-board calibration using a solar diffuser -- a method which is being implemented for MODIS

First to develop a detector-based radiometer for calibration in remote sensing; implemented in a transfer radiometer which can also be used in radiance-based vicarious calibration

CONCLUDING REMARKS

MODIS has an impressive complement of OBCs. However, for several reasons it is important that VC results be also available:

1. Because of the omission of the OBCs from the Engineering Model, preflight experience, trouble shooting, and correction of any OBC problems, will have to be accomplished in a very restricted time frame.

2. There is the possibility that the complex MODIS OBCs, which have not been used before, will not work as planned.

3. It is unlikely that the New Millennium sensors, particularly the MODIS on AM-2, will use the same type of OBCs, *in fact they may not use OBCs at all*. VC will then be even more important than now, as well as being critical to the acquisition of a consistent long-term data set.

In general, the availability of VC methods is key to the success of future missions.